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THE SATIN MOTH, A RECENTLY INTRODUCED PEST

By A. F. BURGESS, *Senior Entomologist, in Charge,* and S. S. CROSSMAN, *Entomologist, Gipsy Moth and Brown-Tail Moth Investigations, Bureau of Entomology*[1]

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INTRODUCTION

On June 22, 1920, H. N. Habberley, at that time superintendent of the Middlesex Fells Reservation of the Metropolitan Park system, brought to the Gipsy Moth Laboratory of the Bureau of Entomology, United States Department of Agriculture, a few larvæ of the satin moth, *Stilpnotia salicis* L. They were found by a crew of park employees, and were defoliating Carolina poplars along the parkway near the Malden-Medford city line, a few miles north of Boston. This parkway is several miles in length and is lined with from two to four rows of Carolina poplars which are about 30 years old.

An investigation made where the caterpillars were collected showed a heavy infestation extending over a small area, and some Lombardy poplars on private property were severely defoliated. The caterpillars were nearly full-grown when the infestation was discovered, and many of them were deserting the trees, swarming over buildings, and in some cases entering houses. (Fig. 3, B, C.) After consultation with the State forester's office and the park superintendent, it was decided to do as much work as was possible to meet the emergency.

The park department began spraying the infested trees in the parkway and stationed a crew of men to patrol the area infested in

[1] After the satin moth was discovered the late F. H. Mosher was detailed to study its life history and habits in connection with his regular duties at the Gipsy Moth Laboratory of the Bureau of Entomology, U. S. Department of Agriculture. He was assisted by J. E. R. Holbrook, who completed certain phases of this work after the untimely death of Mr. Mosher. To these gentlemen credit is given for the life history and information concerning food plants of the insect.

the park and to crush the larvæ, pupæ, and moths and destroy the newly deposited egg clusters. The State forester's office detailed a force of men to search the area outside of the parkway, to determine the immediate limits of the infestation, and to destroy all of the satin moths found. The Bureau of Entomology cooperated by scouting the towns outside of the area where the park department and State forces were working.

The spraying was not so effective as normally, because many larvæ had left the trees for pupation or had pupated in the leaves on the trees. However, the infestation was to some extent reduced by spraying and by the other suppressive methods used.

Scouting operations determined that the infestation was of several years' standing and that the insect had spread over a much larger area than had been supposed. In some of the surrounding towns and cities, where a few isolated defoliated Lombardy poplar trees were found, statements were obtained to the effect that this insect had been present the previous year, but had not been recognized as a new insect in the locality.

It is not known when the satin moth arrived in this country, but it must have been present several years prior to 1920. In many locations large larvæ and pupæ were found in the scouting operations of 1920, indicating that the insect was present in the previous year.

In addition to the suppression and scouting work which was immediately begun, Franklin H. Mosher, of the Bureau of Entomology, stationed at the gipsy-moth laboratory at Melrose Highlands, Mass., investigated the life history of the satin moth and collected data on its habits.

DISTRIBUTION IN EUROPE AND ASIA

This insect is widely distributed throughout Europe and Asia. In some localities it is common and destructive, and a number of distinct varieties or races are recognized in the different regions which it inhabits.

Foreign literature indicates that it is common in central Spain and throughout Italy, also in Russia, the Balkan peninsula, Corsica, Armenia, northeastern Asia Minor, Altai, southeastern Siberia, Urga, Amur, Chosen (Korea), China, and Japan. It has also been reported from the Arctic region and from the British Isles.

Experts of the Bureau of Entomology, detailed on gipsy-moth work in Europe, report it spârsely distributed over most of France, Germany, Poland, Bulgaria, Spain, Italy, Yugoslavia, Hungary, and Czechoslovakia, and medium to heavy infestations have been reported at Dresden, Germany; Luck and Smogulec, Poland; Sofia, Bulgaria; Prague, Czechoslovakia; and Budapest, Hungary. The infestations observed were on poplar and willow trees planted on roadsides and estates. In foreign literature oak foliage has been included as one of the foods of this insect.

In Europe it is not usually considered a very serious pest, being noticed at times of great abundance, when poplar and willow trees are severely defoliated. There is some confusion in foreign literature as to the manner in which this insect hibernates, but the facts that the moths are strong flyers and that they are attracted to lights are mentioned in many articles referring to the satin moth.

NORTH AMERICAN DISTRIBUTION

IN CANADA

In July, 1920, J. D. Tothill found caterpillars of the satin moth defoliating poplar trees in New Westminster, British Columbia. Anxiety was felt by the Canadian authorities when this insect was discovered within their territory, its close relation to the gipsy moth (*Porthetria dispar* L.) and the brown-tail moth[2] (*Nygmia phaeorrhoea* Donovan) placing it in a group of notoriously injurious insects.

R. Glendenning, of the entomological branch, Department of Agriculture, Dominion of Canada, has conducted investigations on this insect, the results of which have been published by the Dominion Department of Agriculture.[3] Lombardy poplar trees on the grounds of Columbia College, at New Westminster, were found to be heavily infested by the satin moth in July, 1920, and during the summer the insect spread to most of the white and Lombardy poplar trees in the city. A few moths were found in a village about 2 miles east of the city. The following year several infestations were located, the worst one being at Vancouver, British Columbia, which was so severe as to indicate that it was the original infestation and that the infestations at New Westminster and other places had originated from Vancouver. At the time of the preparation of the report the infested area included about 50 square miles on the mainland of British Columbia, with several infestations on Vancouver Island.

In the summer of 1923 the senior author visited some of the infested area in New Westminster and noted partial to complete defoliation of poplar and willow trees.

IN THE STATE OF WASHINGTON

The first record of the satin moth in the State of Washington[4] was made at Bellingham in 1922 by W. E. Longley. The insect was first seen on a nearly defoliated row of Lombardy poplars. Later in the season it was discovered in several other places. The specimens were identified at the Dominion Museum at Victoria, British Columbia.

Since that time considerable scouting has been done throughout the western part of the State of Washington, under the direction of A. G. Webb, plant quarantine inspector of the Federal Horticultural Board, who has charge of the port of Seattle. The results of this work indicated that the insect had become established in many localities where poplar and willow trees are present, distributed throughout most of the counties from the international line south to Seattle. As a result of this work the Federal quarantine was extended in the

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[2] In American publications the brown-tail moth has been known since its establishment in the United States as *Euproctis chrysorrhoea* L. It is regrettable that the use of a name which has been employed so long and is so well understood should have to be discontinued. However, evidence has been presented to prove clearly that *E. chrysorrhoea* is the name of another common European insect. BARNES, W., and BENJAMIN, F. H. ON THE CORRECT NAME FOR THE BROWN-TAIL MOTH. Ent. Soc. Wash. Proc. 26 : 213.

[3] GLENDENNING, R. THE SATIN MOTH IN BRITISH COLUMBIA. Canada Dept. Agr. Pamphlet 50, New Series, 14 pp., 1924.

[4] Acknowledgment is gladly made here of the kindness of E. R. Sasscer, of the Federal Horticultural Board, in allowing the writers to refer to a report by A. G. Webb, associate plant quarantine inspector, in regard to the satin-moth situation in the State of Washington.

State, as shown in Figure 1. The details are given later in this report.

IN THE NEW ENGLAND STATES

Data regarding the distribution of the satin moth in New England have been obtained from several sources. Much of the information for Massachusetts has been obtained from the State forester's office of the commissioner of conservation and from the division of plant pest control of the State department of agriculture. The moth superintendents and tree wardens of many of the towns and cities in the State have reported on the conditions in the towns they represent. Information from the other New England States has been

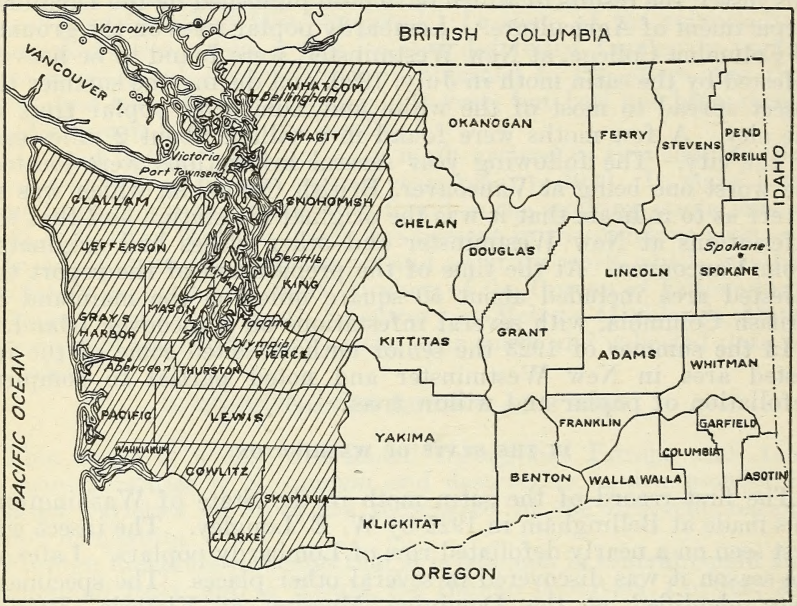


FIG. 1.—Map of the State of Washington. The shaded portion shows the area in this State quarantined against the satin moth. The plus (+), at Bellingham, in the northwestern part, indicates the location of the first infestation of the satin moth found (in 1922) in the State. The small circles (⊙) denote the known infestations in British Columbia in 1924

obtained from State entomologists and other interested parties, and these data have been supplemented by scouting work in Maine by State and Federal employees, and in New Hampshire, Connecticut, and Rhode Island by assistants connected with the gipsy moth and brown-tail moth project. Much information has been collected by employees of this division in connection with their regular duties.

The information obtained during the summer of 1920, when extended scouting was done, showed that this insect had spread over an area of 642 square miles, including 60 towns in Massachusetts and 4 in New Hampshire. Some of this spread occurred in the summer of 1920, but the occurrence of large larvæ and pupæ in the majority of the towns proved that in many cases the insect had been present the previous year.

In 1921, 1922, and 1923 little scouting was done, but an attempt was made to determine the situation in Massachusetts with respect to the satin moth by requesting information from all of the towns known to be infested with it and in a double row of towns bordering the infested territory. The information obtained was furnished by superintendents of local work against the gipsy moth. A similar request for information concerning the situation in the towns in New Hampshire known to be infested, and in those immediately surrounding the infested area, was made to the State entomologist of New Hampshire. As a result of these requests, with information acquired by the Federal force in 1921, four towns in Massachusetts and one in New Hampshire were included in the infested area. In 1922 no newly infested towns were reported. In 1923 two more towns were added to the infested area in Massachusetts; and, of 57 New Hampshire towns that were inspected, 41 were found to be infested.

Very little scouting was done in New Hampshire in 1924, but it resulted in the inclusion of four additional towns in the infested area. In Massachusetts scouting was carried on by inspectors of the State department of agriculture, chiefly in the southern part of the State, by which 34 towns were added to the infested area.

In 1925 many towns were added to the infested territory, and the satin moth was found for the first time in Maine and in Rhode Island. The new records of occurrence of the satin moth were made in 42 towns in Maine, 21 in New Hampshire, 80 in Massachusetts, and 11 in Rhode Island.

Scouting in 1926 resulted in the addition to the area quarantined against this moth of 16 towns in Rhode Island, 2 in Connecticut, 24 in Massachusetts, 24 in New Hampshire, and 32 in Maine.

The present distribution of the satin moth in New England (fig. 2) covers an area of approximately 12,114 square miles. The infested territory lies along the Atlantic coast, covering an area about 60 miles wide and extending from the city of Belfast, Me., to Stonington, Conn.

The spread of this insect in New England has been rapid, and principally toward the north and northeast, as was the case in the dispersion of the brown-tailed moth, the gipsy moth, and several other insects. The record of the yearly distribution, as determined by the reports and scouting records, is merely suggestive of the direction and rapidity of the spread of this insect, for, with the exception of the work done in 1920, 1925, and 1926, no systematic attempt has been made to determine the exact spread of the insect.

DESCRIPTION AND HABITS

THE MOTH

The insect derives its name from the white, satinlike appearance of the moths, which are larger than most of the white moths native to New England and have no colored markings on the wings. (Pl. 1, *3*, *4*.)

Males 15 to 20 mm., females 20 to 25 mm. in length. Wing expanse 35 to 60 mm. Males slightly smaller than females. Head, thorax, and abdomen black, densely covered with long white hairs and scales, giving the moth a

satinlike luster. Hairs often dense at tip of abdomen, giving it a tufted appearance. Eyes black. Shaft of antennæ black, covered dorsally with flat, white scales. Antennæ of males bipectinate; of females, bidentate. Pectinations and dentations brown to black. Legs black, femora densely covered

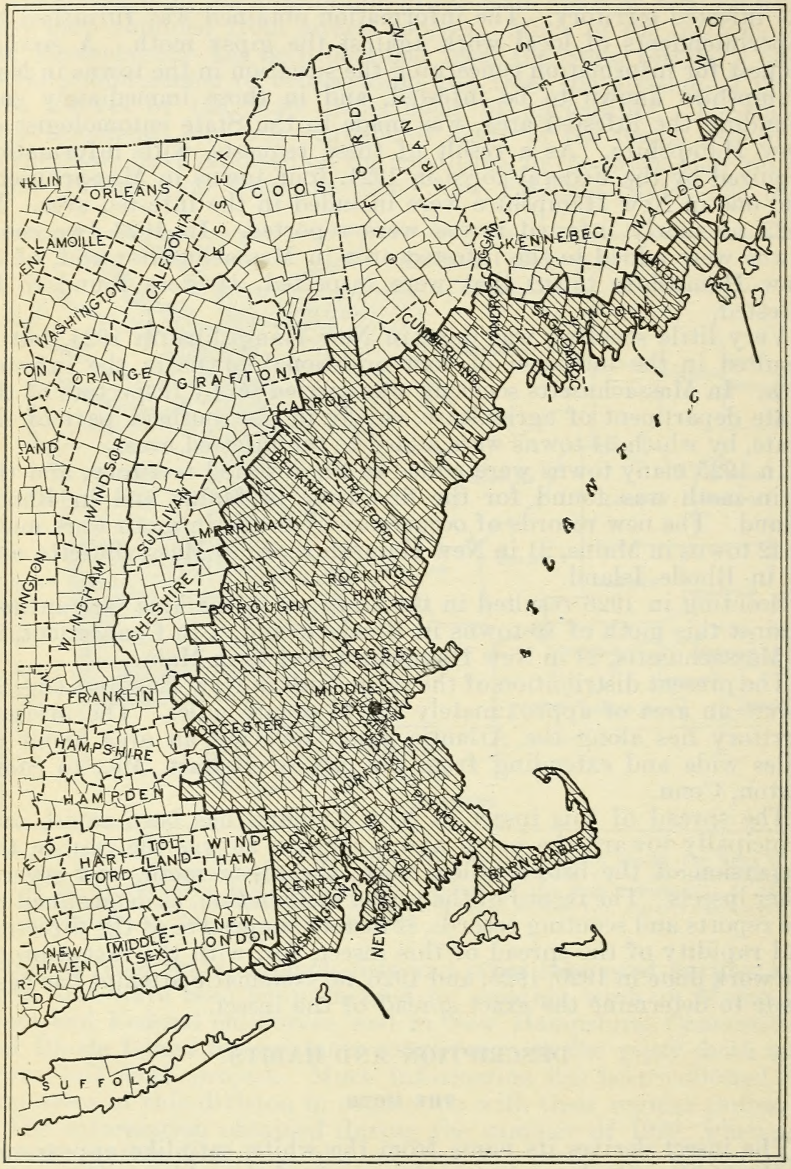
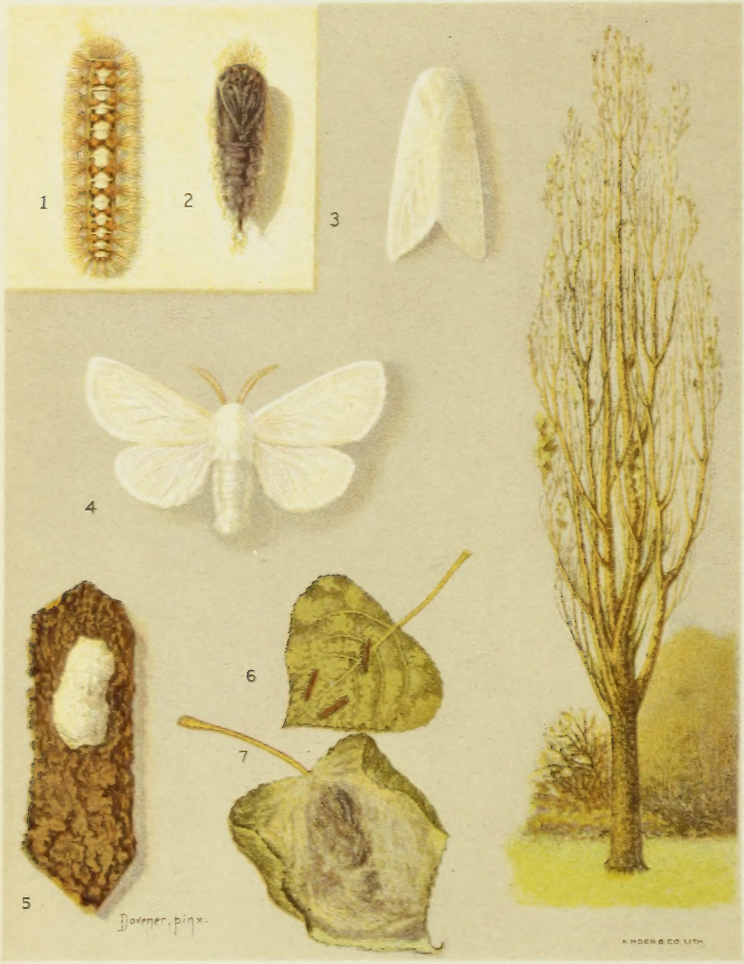


FIG. 2.—Map of the portion of New England in which infestations of the satin moth have been found. The shading indicates the area known to be infested, which is also the area quarantined against this moth. The heavy dot near Massachusetts Bay denotes the location of the original colony, discovered in 1920

with long white hairs. Tibiæ and tarsi sparsely covered with white hairs, ringed with white overlapping scales, giving the appearance of alternate bands of black and white.



DIFFERENT STAGES OF THE SATIN MOTH (STILPNOTIA SALICIS)

1, Full-grown larva. 2, Pupa. 3-4, Moths. 5, An egg cluster on bark. 6, Small larvæ on leaf. 7, Pupa in its cocoon in partially folded leaf. At right, defoliated poplar, with partially defoliated willows in background.

The moths emerge during a period of three to four weeks, beginning in the latter part of June, and are most abundant in the month of July. Those of both sexes are strong flyers and are attracted to lights, especially in the darkness of the early evening. European records indicate that great numbers of moths fly long distances, but such migrations have not been observed in this country. The moths move about during the day and fly short distances when disturbed, but are more active at night and are often abundant around street lights. In laboratory experiments the females have lived from 6 to 20 days, and the average length of life was 10 days.

MATING AND OVIPOSITION

Mating usually takes place within a few hours after emergence. While the moths are in coitu their heads are in opposite directions, and they may remain in that position for several hours. In a heavy infestation mated pairs may be found in this position on trees, grass, or bushes, and in some cases on electric-light poles, or on buildings near by. Both sexes frequently mate more than once, especially if the female has been disturbed during oviposition. The eggs are sometimes deposited near the place where the female emerged, but in many cases a long flight may be made before the eggs are laid.

Egg laying takes place during July, being at its height about the middle of the month. The clusters of eggs are deposited principally on the trunks, the under sides of the branches, and the leaves of trees; but they are also frequently found on fences, stones, buildings, or electric-light poles that are located near trees or brilliant lights. Glendenning[5] reports that—

> Twenty-five egg masses were counted on July 28, 1921, on the faces of the clock on the tower of the Burns Building, Vancouver, British Columbia. This building is nearly 250 feet high, and the clock is illuminated at night, which probably accounts for the eggs being there. This apparent carelessness is, however, no doubt occasionally the means of dispersal to fresh locations, when the eggs are laid on movable objects.

THE EGG

The eggs are laid in patches which are somewhat oval in form, averaging in size 15 mm. long and 12 mm. wide. Each patch is easily seen, being covered with a satin-white secretion which glistens in the sun. (Pl. 1, *5*.)

> Eggs spherical, but slightly flattened; light green when freshly laid, gradually becoming brown as embryo develops.

The number of eggs in egg masses deposited in the field averaged 316, as determined by an examination of large numbers of clusters. The largest mass collected in the field contained 412 eggs. There is a great variation in the size of these clusters, owing to the habit of the female of moving about if disturbed and so depositing more than one mass.

In an experiment involving 46 fertilized females, two deposited over 1,000 eggs each. The greatest number deposited by one female was 1,023, and the average number for the experiment was 571. This number is greater than the average for field records.

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[5] Page 10 of publication cited in footnote 3.

Under laboratory conditions hatching occurred in from 12 to 19 days after egg deposition, the average time being 15 days.

THE LARVA

[Pl. 1, *1, 6;* text fig. 3, B, C, D]

There is a slight variation in the markings of the larvæ, as well as in the length and in the width of the head of the different larval stages. The following descriptions and measurements are for the average larvæ in each stage.

FIRST-STAGE LARVA

Newly hatched larva 2.5 mm. long. Head brownish and 0.43 mm. in width; flat on front, with a few short spines. Mouth parts lighter in color. Thoracic legs brown. Body brownish yellow, with rows of darker brown tubercles, thickly studded with short brown spines and with a small number of long hairs. First thoracic segment provided with brownish dorsal shield.

The first-stage larvæ leave the egg mass soon after hatching and begin feeding on either side of the leaf, but more often on the underside. They eat the epidermis only, avoiding even the smaller veins. After five or six days each larva incloses itself within a small web, where it molts. Very soon after molting the second-stage larva crawls from the molting web and begins feeding.

SECOND-STAGE LARVA

Newly molted larva 4 mm. long. Head 0.55 mm. wide, black, with lighter colored mouth parts. Body dark brown, with rows of dark-brown tubercles thickly studded with short brown spines and a few long hairs. Thoracic legs dark brown to black. First thoracic segment with dark-brown dorsal shield, similar to the one in the first-stage larva. Dorsum of the second and third thoracic segments, and the third, fourth, fifth, eighth, and ninth abdominal segments, yellowish white. Dorsum of the sixth and seventh abdominal segments provided with retractile tubercle.

The second-stage larvæ feed for five to six days, in the same manner as do the first-stage larvæ. Since the larvæ of both stages confine their feeding to the epidermis of the leaves, they do not defoliate the trees as do the larger caterpillars. In heavy infestations the feeding by the small larvæ is often severe enough to cause many of the leaves to turn brown and drop, making the trees unsightly. When through feeding, the larvæ construct hibernating webs, in which, soon after their completion, another molting occurs.

HIBERNACULUM

The web made by the second-stage larva is much stronger than the molting web of the first-stage larva, and within it the third-stage larva passes the winter. Usually there is a single larva within each web, but occasionally, in heavy infestations, several larvæ hibernate under the same web. The hibernating webs (fig. 3, E) are placed in crevices and depressions, ranging from deep to very slight, in the bark on the tree trunks and branches. They are sometimes found on small twigs, and even on leaf scars, and are present from the top to the bottom of the trees. They are very inconspicuous, closely resembling the color of the bark. In shape they are irregular, with a circular or oval outline, usually about 4 mm. in length and 1 or 2 mm. wide. Occasion-

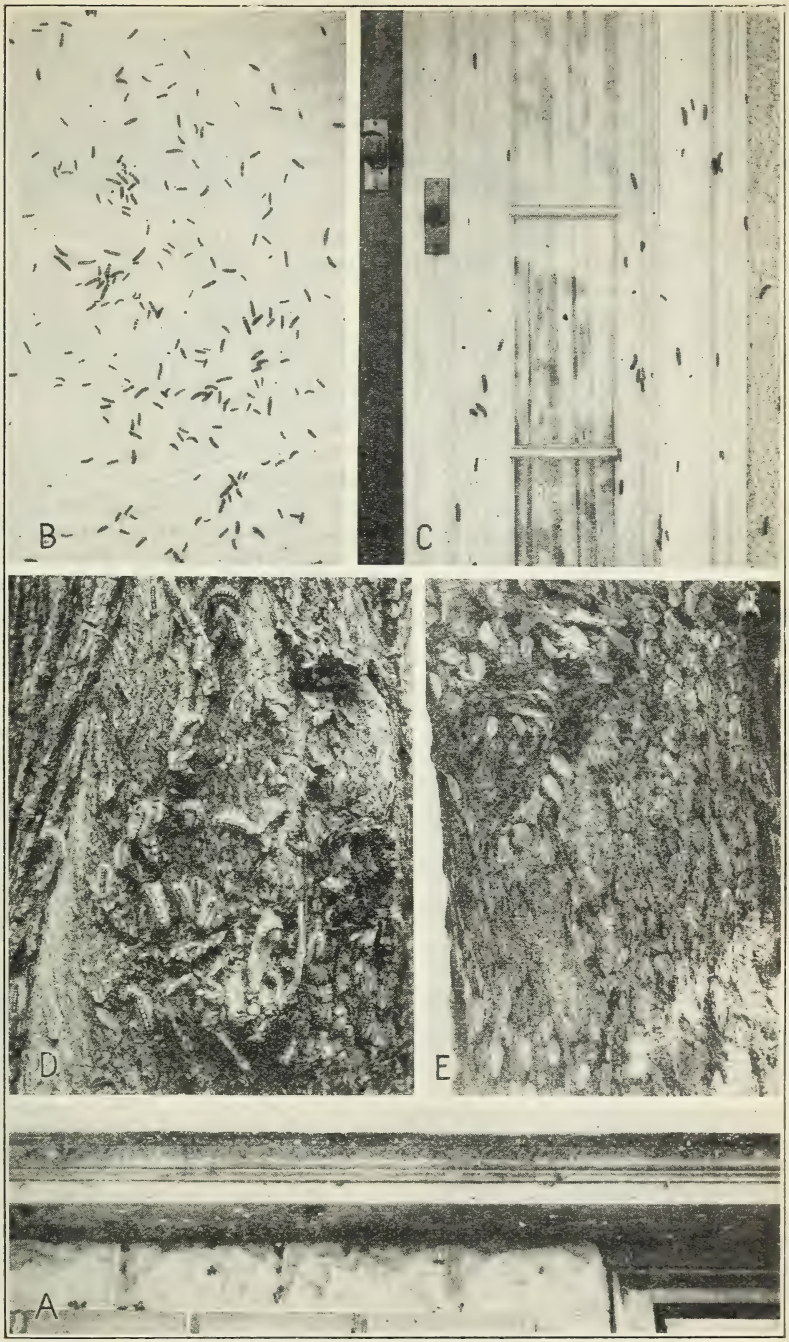

FIG. 3.—A Satin moth pupal cases and egg clusters on garage; B, larvæ on ceiling of porch; C, larvæ on door opening on front porch; D, larvæ on trunk of tree; E, hibernation webs on trunk of tree

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ally a small amount of the bark over which the web is constructed appears to have been excavated. The cavity is lined with fine silk.

THIRD-STAGE LARVA

When first molted, the third-stage larva is about 6 mm. long. In its hibernating web it contracts to about 4 mm. in length. Head black, 0.63 mm. wide. Body slightly darker in color than in second stage; being contracted, it appears much more hairy. Contraction of the body makes the light colors on dorsum more pronounced.

Normally the third-stage larvæ do not feed and do not leave their hibernaculum until the following spring. Occasionally they have been observed crawling on the trees on warm days in the late fall and early winter. Such larvæ have not been known to reenter their hibernating quarters, and those observed died without attempting to construct new ones. In the laboratory experiments which have been performed, third-stage larvæ have not fed or left their hibernating webs at any time during the fall or winter.

In the latter part of April the third-stage larvæ begin emerging from hibernation, the emergence continuing through the first three weeks of May, with a maximum early in the month. After five or six days of feeding, under laboratory conditions, the larvæ inclose themselves in rather coarse webs, in which they molt. In the field, just before molting, the larvæ construct for this purpose webs similar in appearance to the hibernating webs. Only the epidermis of the leaf is eaten by third-stage larvæ.

FOURTH-STAGE LARVA

Newly molted larva 8 mm. long. Head black, 0.95 mm. in width. Body similar to that of third-stage larva, with hairs much longer.

Fourth-stage larvæ feed from five to six days, consuming much more food than larvæ in the previous stages. They do not confine their feeding to the epidermis of the leaves, but eat small, irregular holes, avoiding the larger veins. These larvæ prepare slight webs across the fissures of the bark, beneath which they molt.

FIFTH-STAGE LARVA

Newly molted larva 12 mm. long. Head black, with a slight bluish tinge, 2 mm. in width. Body black, mottled with white markings of irregular shape, which form distinct subdorsal lines on each segment. On the dorsum of the first, and that of the last, body segment is a white irregular blotch. On each of the intermediate segments are two white blotches of irregular shape. These are placed anteriorly and posteriorly on the segments, so that the posterior blotch on each segment combines with the anterior blotch of the one following. These white blotches make the caterpillar conspicuous, and are characteristic of this species. Tubercles in this stage reddish brown, and hairs longer than in preceding stage.

In feeding, the fifth-stage larvæ consume the entire leaf with the exception of the larger veins. This stage occupies five to six days, after which the larvæ prepare their molting webs in the fissures on the tree trunks.

SIXTH-STAGE LARVA

Newly molted larva 25 mm. long. Head black with bluish tinge; 3 mm. wide. Markings similar to those of previous stage. White blotches larger and more conspicuous, and brown tubercles brighter in color than on fifth-stage larva. White mottling of black body, giving it a light bluish-gray appearance.

The sixth-stage larvæ feed for five to six days, eating the entire leaf tissue, and leaving only the coarser veins. As in the case with the previous stages, the sixth-stage larvæ construct webs across the fissures of the bark, under which they molt.

SEVENTH-STAGE LARVA

Newly molted larva 35 mm. long. Head black with a bluish tinge, 4.5 mm. wide. The caterpillar has the same appearance as in the sixth stage, but is considerably larger and more conspicuous. (Pl. 1, *1*.)

The seventh-stage larva feeds for about seven days, then spins a loose cocoon in which to pupate.

THE PUPA

Pupa (Pl. 1, *2*, *7*) 20 to 25 mm. long and 5 to 7 mm. wide at base of abdomen. Shining black, covered with tufts of long, silky, white and golden hairs, except on venter, where hairs are scarce. Usually on each abdominal segment occurs a row of two to five light-brownish spots, variable in size and number and occasionally missing.

Pupation takes place after the seven larval stages which have been described, both male and female moths developing from seventh-stage caterpillars. The cocoon, the spinning of which may occupy from several hours to two days, is very loosely made, and the pupa within is plainly visible. It is frequently constructed so as partially to bring together the two edges of a leaf, as shown in Plate 1, *7*. The cocoons occur not only on leaves, but are also found in the crevices of bark, in rubbish near trees, and on buildings, fences, and in other convenient places. (Fig. 3, A.) The adult emerges about 10 days, on an average, after construction of the cocoon is begun.

FOOD PLANTS

Field observations and feeding experiments have been made at the Gipsy Moth Laboratory to determine the favored food plants of the satin moth in New England. As a result the trees here named have been listed in the order of their preference as food plants of the satin moth.

FAVORABLE

Lombardy poplar	*Populus nigra italica* DuRoi.
Carolina poplar	*Populus deltoides* Marsh.
Balm of Gilead	*Populus candicans* Ait.
White poplar	*Populus alba* L.
Large-tooth aspen	*Populus grandidentata* Michx.
Quaking aspen	*Populus tremuloides* Michx.
Golden willow	*Salix vitellina* L.

PARTIALLY FAVORABLE

Scrub oak	*Quercus ilicifolia* Wang.
Black oak	*Quercus velutina* Lam.

NONFAVORABLE

Alder	*Alnus incana* (L.) Moench.
Apple	*Pyrus malus* L.
Gray birch	*Betula populifolia* Marsh.
Elm	*Ulmus americana* L.
Red oak	*Quercus borealis maxima* (Marsh.) Ashe (*Q. rubra* auct.).
White oak	*Quercus alba* L.
Scarlet oak	*Quercus coccinea* Moench.
Pear	*Pyrus communis* L.
Red maple	*Acer rubrum* L.
Paper birch	*Betula papyrifera* Marsh.
White ash	*Fraxinus americana* L.
Hickory	*Hicoria ovata* (Mill.) Britton.

From the time of hatching to the adult stage the larvæ of the satin moth feed on the food plants listed as favorable, but have seldom been observed under field conditions to attack the species listed as partially favorable. Glendenning [6] reports that the insect was noted sparingly on the native cottonwood, *Populus trichocarpa* Torr. & Gray, at New Westminster, British Columbia, and A. G. Webb has found the larvæ feeding on this and on willow trees in the State of Washington.

Larvæ of the satin moth have not been reared from hatching to maturity on the trees listed as partially favorable, but fed through the first two fall stages and hibernated successfully with no other food than scrub oak. Emerging in the following spring as third-stage larvæ, they began feeding on scrub-oak leaves in the laboratory, but died without molting. Larvæ which fed on poplar during the first two stages in the fall were successfully reared to maturity on scrub oak the following spring. The feeding experiments have indicated that black oak is less favorable than scrub oak. Larvæ which have had only black-oak foliage for food have been reared through the first two stages and lived through the winter; but in the spring, when black oak was the only food supplied, they died without further development. Larvæ which were fed on poplar only during the first two stages, and hibernated successfully, were fed on black oak during the following spring; they developed slowly, and in no case reached maturity.

The foliage of the trees listed as nonfavorable has been tested for several years as food for larvæ of the satin moth. In no case have caterpillars developed to the hibernating stage when restricted for food to any of the trees listed in this group.

ARTIFICIAL CONTROL

In cases where the satin moth is abundant and many egg clusters are deposited the latter can be destroyed by treating them with creosote. *This treatment should be applied as soon as possible after the eggs are laid, as hatching takes place in from 10 to 20 days after the time of deposit, and after the eggs have hatched the treatment is futile.* Crude coal-tar creosote, to which a small quantity of lampblack is added, so as to leave a black residue on the treated clusters, will be satisfactory. It should be applied with a brush; if this is attached to a pole many of the clusters on the trunks

[6] See p. 4 of publication cited in footnote 3.

and lower branches of the trees can be reached. In eastern New England the poplars and willows are usually attacked by borers, so that many of the large limbs are in a weakened condition, and as the wood is naturally very brittle it is usually inadvisable to climb the trees in order to apply treatment.

If the infestation is extremely heavy or the larvæ swarm on buildings or enter houses, they can be swept to the ground and killed by crushing. Cases are on record where the larvæ were washed from buildings by using water pressure, and afterwards were crushed on the ground.

Experience has shown that the most effective treatment for the satin moth is to spray the trees infested by it with arsenate of lead (fig. 4) during the period when the caterpillars are feeding.

FIG. 4.—Carolina poplars. The foliage on the trees in the rear was sprayed with arsenate of lead. The trees in the foreground were not sprayed, and were heavily fed upon by larvæ of the satin moth.

As the eggs are deposited anywhere on the trees, the feeding by the young larvæ is well distributed on the foliage. It is not necessary to spray in August unless the infestation is very heavy. Should this be the case, an even distribution of the poison will give excellent results. If the spray is applied as soon as the larvæ begin to feed it will be most effective. Both sides of the foliage should be sprayed.

Summer spraying will not as a rule be necessary. In the spring, as soon as the trees are in full leaf, treatment should be applied. A high-pressure sprayer is required in order to treat the tops of the trees. A machine of this type, using a solid-stream spray, has given excellent results in Massachusetts, when arsenate of lead was applied at the rate of 6 pounds of powder to 100 gallons of water.

Because of the smooth surface of the foliage of poplar and willow trees, the poison does not adhere to it as well as to other types of foliage. Recent experiments at the Gipsy Moth Laboratory indicate that excellent adhesion can be obtained by adding 3 quarts of

fish oil, or, if this is not available, the same quantity of raw linseed oil, to each 400 gallons of spray. The oil should be poured into the spray tank while it is being filled with water and after the poison has been added. The contents of the tank should be thoroughly agitated while the oil is poured in and until the mixture is applied.

This spray will adhere very closely to the foliage and is affected very little by rain. Care should therefore be exercised to prevent cattle from feeding on the grass beneath sprayed trees. Buildings will be discolored with this spray unless care is taken to wash them with water from a garden hose before any poison adhering to them is thoroughly dried.

NATURAL ENEMIES

One of the interesting features of the introduction of an insect into a new region is the question whether it will be attacked by natural enemies present in its new home.

NATIVE PARASITES

Several native parasites have been found attacking the satin moth in New England, although the rate of parasitism is small. The following species were reared from this insect at the Gipsy Moth Laboratory:

Reared from eggs.—Telenomus californicus Ashm.
Reared from larvæ.—Zenillia blanda O. S., *Frontina frenchii* Will., and *Phorocera claripennis* Macq.
Reared from larvæ and pupæ.—Tachina mella Walk. and *Winthemia quadripustulata* Fab.
Reared from pupæ.—Theronia fulvescens (Cress.), *Ephialtes pedalis* (Cress.), *Itoplectis conquisitor* (Say), and *Dibrachys hemerocampae* (Girault).[7]

Of native parasites *Telenomus californicus* is the most common. During the summer of 1925, satin-moth egg clusters were received at the laboratory from 66 towns in New England, from 19 of which this egg parasite was recovered. These data are especially interesting, as the collections, each consisting of a single egg cluster, were mostly taken from new infestations in towns on or near the border of infested territory.

Two species of Tachinidae, three species of Hymenoptera, and three sarcophagids have been mentioned as natural enemies of the satin moth in British Columbia. The tachinids *T. mella* Walk. and *T. robusta* Tn. appear to be of considerably more value there than any native parasite has been in New England. Glendenning [8] writes as follows of observations made in 1922 of infestations in New Westminster, British Columbia, where from 25 to 80 per cent of the caterpillars had tachinid eggs on them:

> The majority of these eggs, being laid shortly after the last larval molt, hatched before being shed at pupation, and the great majority thus proved fatal to their hosts and were an appreciable control factor in this location.

Another quotation from Glendenning [8] follows, indicating the abundance of native tachinids at an infestation on Vancouver Island.

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[7] Determined by A. B. Gahan, of the Bureau of Entomology. The other Hymenoptera and Diptera were determined by C. F. W. Muesebeck, R. T. Webber, and T. H. Jones, of the Gipsy Moth Laboratory.

[8] See p. 13 of publication cited in footnote 3.

In Nanaimo, in 1922, the white eggs were very abundant, but owing to the immense number of larvæ present the percentage was only about 35 * * * Numbers of larvæ collected here contained so many maggots of apparently equal vigor that very few completed their feeding and but few puparia were obtained.

In addition to *T. mella* and *T. robusta*, three sarcophagids, *S. houghii* Aldr., *S. aldrichii* Pk., and *Agria affinis* Fall., and three Hymenoptera, *Ephialtes pedalis* (Cress.), *Theronia fulvescens* (Cress.), and *Amblymerus liparidis* Vier., are recorded as being parasitic on the satin moth in British Columbia. They were considered to be of little importance as control factors.

PREDATORY ENEMIES

Birds undoubtedly consume many larvæ of the satin moth. Mosher made some special studies to determine the relationship of birds to the satin moth and recorded the following species as feeding on them: Black-billed cuckoo, *Coccyzus erythrophthaimus;* oriole, *Icterus galbula;* blue jay, *Cyanocitta cristata cristata;* starling, *Sturnus vulgaris*, and catbird, *Dumetella carolinensis.* On numerous occasions the junior author has noted blue jays and starlings apparently picking the small satin moth larvæ from their hibernating webs on heavily infested poplar trees. Western robins and bats have been reported as feeding on the satin moth at New Westminster, British Columbia. Toads have been observed to take the larvæ, and several spiders have also been noted as their enemies.

DISEASE

There is no positive evidence that larvæ of the satin moth are attacked in this country by the disease commonly known as "wilt." Larvæ are occasionally observed in the field attached to the tree trunks by their anal prolegs, with the head hanging downward in a position similar in appearance to the characteristic position in which caterpillars are found which have died from the wilt. On two of these occasions, when the situation was further investigated, it was found that in one place the foliage had been sprayed, indicating that the larvæ had been poisoned. At the other location several dead larvæ were examined, and each one was found to contain a tachinid maggot.

In the food-plant experiments which have been carried on at the laboratory for the last few years there has been no evidence that the larvæ die from wilt. However, in some of the large trays used for feeding large numbers of satin moth larvæ which had been collected to obtain Compsilura for colonization, caterpillars have been found which had the characteristic appearance of having died from wilt. In the summer of 1925 a number of these dead larvæ were sent for examination to R. W. Glaser, of the Rockefeller Institute, who reported that in this material there was no evidence of the wilt disease.

EFFECT OF INTRODUCED ENEMIES OF THE GIPSY MOTH AND BROWN-TAIL MOTH ON THE SATIN MOTH

The gipsy moth and the brown-tail moth became established in the New England States in the utter absence of the insect enemies which attack them in the Old World, but this is not the case with the satin

moth. Several of the insect enemies of the gipsy moth and the brown-tail moth which have been introduced and established are also enemies of the satin moth.

Numerous observations have been made, and collections of various stages of the satin moth obtained, to determine the status of the natural control of this insect in New England. Absolute records have been obtained showing that *Compsilura concinnata* Meigen, *Calosoma sycophanta* L., and *Blepharipa scutellata* R. D. have attacked the satin-moth larvæ in the field. These three introduced insects are among the most important enemies of the gipsy moth that have been successfully established.

B. scutellata has not as yet been an important enemy of the satin moth, but the fact that it is able to develop as a satin-moth parasite gives it a potential value, and under certain conditions it may become important.

Adults of *Calosoma sycophanta* are often seen climbing over the trees and feeding on satin-moth larvæ. They attack these larvæ readily, and the evidence of their work is often observed. Many satin-moth larvæ which have been killed or injured by the beetles have been found on the tree trunks and on the ground at the base of the trees. The observations which have been made indicate that the Calosoma larvæ appear too late in the season to be of primary importance as enemies of the satin-moth caterpillars. Moreover, the habit of many of the satin-moth larvæ of pupating in partially folded leaves protects them still further from the attacks of Calosoma larvæ.

TABLE 1.—*Parasitism of satin-moth larvæ and pupæ by Compsilura concinnata in New England from 1922 to 1924, as shown by rearings*

Town	Year	Medium-sized larvæ collected	Compsilura recovered	Large-sized larvæ collected	Compsilura recovered	Pupæ collected	Compsilura recovered
Revere	1922	100	1	100	11	100	0
Do	1923	100	0	100	7	100	3
Do	1924	100	1	100	56	100	5
Melrose	1922	100	12	100	44	112	16
Do	1923	100	22	100	71	100	29
Do	1924	100	2	100	66	100	35
Medford	1922	100	10	100	50	100	16
Do	1923	100	6	100	63	100	11
Do	1924	100	4	100	71	100	0

Up to the present time *Compsilura concinnata* has been the principal insect enemy of the satin moth in New England. Table 1 shows the value of this introduced tachinid as an enemy of the satin moth.

The data obtained during the summer of 1925 from collections of medium-sized and large caterpillars are presented in Table 2.

The larval and pupal collections shown in Tables 1 and 2 were kept in trays at the laboratory, and were cared for until the emergence of the parasites. The recoveries from these collections indicate the abundance of *C. concinnata*, and distinctly show how readily it is attacking the satin moth, but these figures are not presented to show the actual percentage of parasitism of the satin moth

in the localities represented. Sufficient study has not been made to determine that.

TABLE 2.—*Parasitism of satin-moth larvæ by Compsilura concinnata in New England in 1925, as shown by rearings*

Town	Larvæ collected	Compsilura recovered
Melrose, Belmont, Haverhill	[1] 10,680	3,062
Revere	200	16
Beverly	29	1
Eastham	54	1
Total	10,963	3,080

[1] In the laboratory experiments several collections from these three towns were combined.

In addition to the larval collections shown in the foregoing tables, dissections were made of medium and large-sized satin-moth larvæ collected at the towns listed in Table 3.

TABLE 3.—*Percentage of satin-moth larvæ parasitized by Compsilura concinnata in New England in 1925, as shown by dissections*

Town	Larvæ collected	Larvæ parasitized	Percentage of larvæ parasitized
Dennis, Mass.	150	0	0
Westwood, Mass.	1	0	0
Worcester, Mass.	200	87	43.50
Lowell, Mass.	3	2	66.67
Seabrook, N. H.	200	2	1.00
Concord, N. H.	50	8	16.00
Laconia, N. H.	16	6	37.50
Total	620	105	16.94

The larval dissections listed in Table 3 show in a number of cases more than one parasitic maggot in each caterpillar. Such superparasitism by Compsilura occurs in a number of different hosts, and, although it is a waste, it is not as disastrous as might appear. In the case of the satin moth and of several other species superparasitism is seldom excessive, and the host is large enough to support two and sometimes more Compsilura maggots without apparent weakening of the resulting adult parasites.

One hundred satin-moth larvæ were collected at Quincy, Mass., in 1924, and upon dissection were found to have an unusual degree of superparasitism. Forty-two contained no parasites, but the remaining 58 were parasitized by 77 Compsilura maggots. It seems evident that Compsilura larviposits in its host at random, and in this case an unnecessarily large number of parasites were present in some of the hosts. Each of 35 larvæ contained 1, each of 13 contained 2, and 1 contained 3, first-stage maggots; 7 were found to

contain 1, and 1 to contain 2, second-stage maggots; and 1 larva was parasitized by 1 second-stage and 3 first-stage maggots.

In connection with the gipsy-moth work large collections of gipsy-moth caterpillars have been made each year, from which Compsilura have been obtained for colonization. There have been few heavy gipsy-moth infestations in and around Melrose in recent years, and as the satin moth is an attractive host for Compsilura large numbers of satin-moth caterpillars have been collected from which Compsilura for colonization were obtained. The favorable food plants of the satin moth are often planted in groups, and as only poplar and willow trees have been affected it has been possible to make collections of larvæ very rapidly from a heavily infested locality.

Besides the records obtained pertaining to *Compsilura concinnata*, *Calosoma sycophanta*, and *Blepharipa scutellata*, field observations have strongly indicated that another one of the introduced and established gipsy-moth larval parasites, *Apanteles melanoscelus* Ratz., attacks satin-moth larvæ in the field.[9]

Another species, *Apanteles vitripennis* Hal., a very common braconid parasite of gipsy-moth larvæ in Europe, has been colonized in New England in the last two years. It is not as yet positively established, although since colonization it has passed through a generation in the field. In laboratory experiments it attacks small satin-moth larvæ. It apparently needs a host in which to hibernate, and several unsuccessful attempts have been made to induce it to hibernate in small satin-moth larvæ. It has not been conclusively shown, however, that *A. vitripennis* can not under field conditions pass the winter within hibernating satin-moth larvæ. In the spring of 1925 a few hibernating satin-moth larvæ were collected at North Hampton, N. H., where a colony of *A. vitripennis* was liberated in 1924. Several of these larvæ were dissected by C. F. W. Muesebeck, of the Gipsy Moth Laboratory, and in one of the caterpillars a hibernating Apanteles larva was found. It was not possible to determine the species of this braconid and no parasites were reared from the remaining larvæ of the collection.

A parasite of the gipsy-moth egg, *Schedius kuvanae* How., introduced from Japan, attacks readily and successfully the satin-moth eggs when they are exposed to it in laboratory experiments, and may under favorable conditions attack them in the field.

Rather limited observations have been made to determine the degree of mortality of hibernating satin-moth larvæ in New England; up to the summer of 1925 it seemed to be slight. Examination of the hibernating larvæ in several localities in the spring of 1926 showed 45 per cent larval mortality. A mortality of 2.6 per cent may be attributed to a fungus associated with a few of the dead larvæ, and a mortality of 20.7 per cent appeared to have been brought about by a small pteromalid. Maggots of this parasite were found feeding externally on the satin-moth larvæ in hibernation webs. On examination of pieces of bark heavily infested with hibernating satin-moth larvæ, many of the caterpillars in small areas on the bark were found to be dead, and apparently flattened, as

[9] CROSSMAN, S. S. APANTELES MELANOSCELUS, AN IMPORTED PARASITE OF THE GIPSY MOTH. U. S. Dept. Agr. Bul. 1028. 25 pp., illus. 1922.

though the body fluids had been extracted. In every such case one of these parasite maggots was found in the immediate area, strongly indicating that the pteromalid parasite travels from one hibernating web to another close by, and in the course of its development consumes several caterpillars.

Adults of these parasites have been determined as *Eupteromalus nidulans* (Foerster),[10] a parasite of the hibernating larvæ of the brown-tail moth which is well established in New England as a result of parasite introduction in connection with work on the gipsy moth and brown-tail moth.

The causes of the remaining 21.7 per cent mortality of the hibernating larvæ are unaccounted for. Part of it may be due to mites which are found in considerable numbers in the webs containing the dead larvæ. It should be noted that in the area where the observations were made no unusual winter temperatures have occurred since these observations were begun.

Mortality in New Westminster, British Columbia, due to *Spicaria* sp., a fungous disease, has been reported by Glendenning[11] as amounting to 90 per cent in the season extending from November to March, 1920–21, and again in 1921–22, at Vancouver and New Westminister. At Nanaimo the mortality was not nearly so great. Climatic conditions in this section vary so greatly from those obtaining in the Eastern States that mortality records are not comparable. During the humid season on the Pacific coast conditions are very favorable for the growth of fungous diseases, and this fact accounts for the high mortality recorded.

Individual egg clusters vary greatly in the proportion of eggs that hatch. Of the satin-moth eggs in clusters collected in the field, from 30 to 95 per cent hatched, the average being 80 per cent. Many of the larvæ which hatch from eggs deposited on rocks, fences, buildings, and other objects must die without finding any favorable food plant. Such mortality may be high in heavy infestations.

ECONOMIC IMPORTANCE

It is hazardous to predict the extent of injury likely to be caused by the establishment of a foreign insect in a new environment. The observations made since the satin moth was first discovered in this country indicate that this insect is largely restricted for food to a rather limited group of trees—the poplars and willows. Up to the present time in the infested area most of the feeding has been done on trees planted for shade in parks and along roadways, or on trees planted for ornamental purposes on estates. Most of these trees are of rapid-growing varieties, and many of the small branches on Lombardy poplars have died after suffering severe defoliation. Complete defoliation of large white poplars has caused the death in whole or in part of the trees attacked. In severe infestations the trees are defoliated, and enormous numbers of the large caterpillars migrate in search of food. They then become a nuisance, dropping on pedestrians, crawling up and down trunks of

[10] Determined by P. B. Dowden and A. B. Gahan, of the Bureau of Entomology.
[11] See p. 12 of publication cited in footnote 3.

trees, upon sidewalks, fences, and buildings, and even entering dwellings. The feeding of small larvæ in the early fall is sometimes so severe as to cause a browning and premature dropping of the leaves.

No heavy feeding of this insect in New England was observed, except on poplars (fig. 5, B), until the summer of 1925, when willows (fig. 5, A, C) were also severely defoliated. Experiments on food plants have shown that this insect can mature when scrub oak forms a large part of its food. Similar experiments suggest that larvæ of the satin moth might mature when black oak is a part of their diet. Such data, together with a European report including oak as one of the food plants of these larvæ, leave open the possibility that under certain conditions this insect may attack some trees not at present included in the list of its favored food plants.

There are certain areas in this country where poplar is an important pulp tree and is being planted for that reason. In some areas on Cape Cod, Mass., white poplars are the predominating shade trees, and severe injury to them will result from heavy defoliations caused by this insect.

In many sections in the West trees of the genus Populus constitute the predominating shade and ornamental trees. Should this insect become established in such areas, it might become a pest of the first magnitude.

QUARANTINE

The habit of this insect of hibernating under very small and inconspicuous webs on the trunks of trees (fig. 3, E) and small branches of its favored food plants makes it impossible to inspect nursery stock properly and be sure that it is free from infestation. In order to protect the territory in this country not infested by this introduced insect, a quarantine, No. 53, was promulgated by the Secretary of Agriculture and made effective on and after January 1, 1922. It has been revised annually, the last revision being effective November 15, 1926. This quarantine prohibits the movements of all species and varieties of poplar (Populus) and willow (Salix) trees, and parts thereof capable of propagation, from the area designated as infested to noninfested territory.

The area designated as infested by the satin moth comprises the city of Bangor, Me., and the following towns and all the territory between them and the Atlantic Ocean:

Vinal Haven, North Haven, Islesboro, city of Belfast, Northport, Lincolnville, Hope, Union, Waldoboro, Nobleboro, Newcastle, Alna, Dresden, Gardiner, Richmond, Bowdoin, Webster, Greene, Auburn, Poland, Casco, Naples, Sebago, Hiram, and Porter, *Maine;* Eaton, Conway, Madison, Tamworth, Moultonboro, Meredith, Sanbornton, Franklin, Salisbury, Warner, Henniker, Deering, Bennington, Greenfield, Peterboro, Jaffrey, Sharon, and New Ipswich, *New Hampshire;* Ashburnham, Winchendon, Templeton, Phillipston, Athol, Barre, Oakham, Spencer, Brookfield, Brimfield, Sturbridge, Southbridge, and Dudley, *Massachusetts;* Thompson, *Connecticut;* Burrillville, Glocester, Foster, Coventry, West Greenwich, Exeter, Hopkinton, and Westerly, *Rhode Island;* Stonington, *Connecticut.*

The following counties and all the territory between them and the Pacific Ocean are designated as infested by the satin moth:

Whatcom, Skagit, Snohomish, King, Pierce, Lewis, and Skamania, *Washington.*

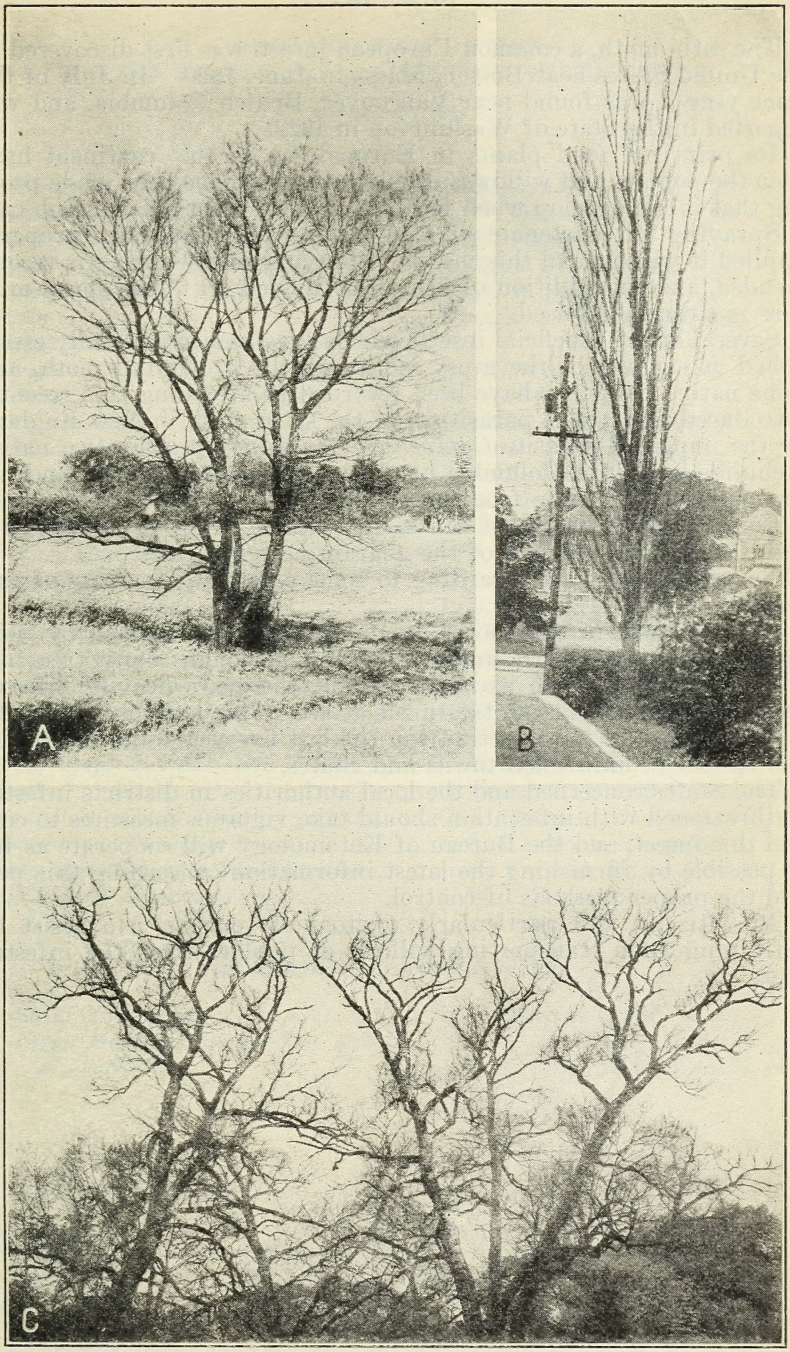

FIG. 5.—A, C, Willows; B, Lombardy poplar. These trees, all in New England, were defoliated by the satin moth, the willows in 1925

SUMMARY

The satin moth, a common European insect, was first discovered in the United States near Boston, Mass., in June, 1920. In July of the same year it was found near Vancouver, British Columbia, and was reported in the State of Washington in 1922.

Its principal food plants in Europe and on this continent have been the poplars and willows, although records have been made proving that it can develop when fed for a part of the time on scrub oak.

Spraying with arsenate of lead has proved that when properly applied it will control this insect. Spraying in the spring is recommended, and the addition of fish oil or linseed oil to the spray mixture is strongly advised.

Several of the beneficial insects which have been successfully established as enemies of the gipsy moth and the brown-tail moth, and some native parasites, have been recorded as attacking this recently introduced pest. The parasitism of the satin moth in New England by the imported parasite *Compsilura concinnata* and by two native tachinids in British Columbia has been especially noticeable and has prevented many larvæ from maturing.

Long-distance spread of the satin moth is being prevented as a result of the enforcement of the quarantine regulations.

Natural enemies are retarding to some extent the increase of this insect.

Control work in the New England States is performed by individuals or by the local authorities, and although many trees are sprayed annually with excellent results, there are heavily infested sections which receive no treatment at all. This has resulted in the rapid increase of the insect during the last five years and its continued spread to uninfested towns and States.

The States concerned and the local authorities in districts infested or threatened with infestation should take vigorous measures to control this insect, and the Bureau of Entomology will cooperate as far as possible by furnishing the latest information concerning this pest and the proper methods of control.

All citizens, and particularly visitors or tourists, can assist by refraining from transporting willows or poplars from the infested area.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

January 18, 1927

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This bulletin is a contribution from

Bureau of Entomology	L. O. HOWARD, *Chief.*
Gipsy Moth and Brown-Tail Moth Investigations	A. F. BURGESS, *Senior Entomologist, in Charge.*

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